Utility Asset Management Programming: Performance, Sustainability and Resilience – Moving from Academia to Practice

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Abstract

Many utility asset management programs have been developed following the U.S. Environmental Protection Agency (EPA) core definition of maintaining a level of service at the lowest life cycle cost. Most utilities, however, only incorporate performance measures into their asset management plans. A holistic approach to asset management is more beneficial because it takes into account the short and long term goals of the utility and can provide better service socially, economically, and environmentally.

An analysis of the Town of Blacksburg wastewater utility's practices and data collection was performed using a holistic asset management framework developed at Virginia Tech. This theoretical framework supports the three key aspects of asset management: performance, sustainability, and resilience. Where gaps were identified, recommendations were made as to what practices, goals, and data the Town can add to their current plan so that their program is more holistic.

Research has shown that many utilities have trouble adapting to asset management plans because job roles and responsibilities change and are often not well defined. To help the Town of Blacksburg adapt to their new asset management plan with performance, sustainability and resiliency goals, a work process flow was designed. A work process flow allows for visible changes in job responsibility to be more easily recognized as well as allow for future changes to be made.

Acknowledgements

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Chapter 1: Introduction and Objectives

Many wastewater utilities in the United States, like the Town of Blacksburg, are looking for ways to increase their level of service (LOS) at the lowest cost. This, by definition according to the Environmental Protection Agency (EPA), is called asset management, and many utilities have begun to adopt asset management plans (AMPs). However, many AMPs are not complete or are only partially adopted. A holistic AMP is a strategy that includes three key aspects: performance, sustainability, and resilience. By adopting a holistic AMP, utilities will benefit from both short-term and long-term goals and can provide better service socially, economically, and environmentally.

In coordination with Virginia Tech's Sustainable Water Infrastructure Management (SWIM) laboratory and the Town's Engineering and GIS department, the goal of this project is to bridge the gap between academic asset management theory and applied AMPs. With the use of the holistic asset management framework developed by Dr. Sunil Sinha, Ph.D., an analysis was performed to identify the Town's wastewater utility practices and data that support performance, sustainability, and resilience. This analysis will identify what data the Town already has in place to support the three key aspects of asset management. Where gaps are identified, recommendations will be made as to what practices, goals, and data the Town can add to its current plan so that performance, sustainability, and resiliency can be included into the organizational structure.

To bridge the gap between academia and practice, both theory and organizational operations need to be understood. Asset management has been explored by many organizations, and simple to complex plans have been developed. Utilities, like the Town, have begun to adapt their former management practices to create more proactive plans that may or may not follow a structured AMP. By recognizing the strengths and weakness in both current utility practice and academia approaches to asset management, a more comprehensive and usable AMP can be established.

The scope of this project is to analyze the Town of Blacksburg's wastewater utility management program and to create a work process flow to incorporate a holistic asset management plan that integrates performance, sustainability, and resilience into the organization's wastewater utility management practices and decision-making. To meet the needs of this scope, the following objectives have been identified.

1. Review literature to gain an understanding of a theoretical asset management framework.
2. Identify data collection and analysis procedures for a holistic AMP.
3. Investigate a real-world application.
4. Determine gaps between AMP theory and real-world applications.
5. Make recommendations, and create a work-process flow that facilitates the integration of a holistic AMP into organizational practices.

Chapter 2: Background

In the past decade, many organizations in the United State have published numerous resources pertaining to infrastructure asset management for water and wastewater utilities. Organizations, such as the EPA and the American Water Works Association (AWWA), have been pushing utilities to move from reactive infrastructure management programs to proactive ones. The EPA defines asset management as "a planning process that ensures that you get the most value from each of your assets and have financial resources to rehabilitate and replace them when necessary." (2008) Literature discusses different types of asset management plans that range from very simplistic to very complex. However, the different plans share a common goal: move utilities away from a reactive mode of maintenance. Reactive approaches can pose larger financial burdens, resulting in an inadequate use of resources and undiscovered issues (EPA, 2002). The implementation of asset management plans can help utilities migrate to proactive operation and maintenance, provide long-term life-cycle cost plans, and employ capital replacement plans based on cost benefit analyses (EPA, 2002).

2.1 Challenges Facing Wastewater Utilities

The EPA estimates that there may be up to $1 trillion worth of repairs needed to bring the United States water and wastewater infrastructure up to recommended standards by 2025 (UIM, 2008). This financial burden for the wastewater infrastructure alone is an enormous undertaking for any one utility and cannot be managed without strategic planning. One major issue that utilities face when dealing with their wastewater infrastructures is that there is no nationwide inventory of sewer pipeline (EPA, 2002). A study done by the American Society of Civil Engineers (ASCE) in 1999 estimated that there was almost 1.2 million miles of sewer serving the

US population. Due to rapid urban growth as well as increases in failing infrastructures, a more accurate estimate of the miles of pipeline across the nation cannot be determined. However, other countries such as the UK and Australia have faced similar challenges of failing infrastructures and have adopted AMPs to help mitigate their problems in cost-effective ways (Williams et al, 2013). AMPs provide utilities with procedures, behaviors, and decision-making tools that can help utilities face financial and public health burdens that occur with failing wastewater infrastructure. The long-range planning, proactive maintenance, and capital replacement plans included in asset manage can be an effective method of facing the present challenges (EPA, 2002).

2.2 Benefits of Asset Management

Applying an AMP to an organization is beneficial in many ways. First, it increases an organization's knowledge of its system (EPA, 2003). Better understanding of a system can result in more sustainable decision-making, economically, and even socially and environmentally. Without useful information, an organization will blindly make decisions that can cost municipalities money they don't need to spend as well as cause problems for the citizens or environment. For example, unnecessary digging to replace underground pipes that may not be in need of repair wastes financial resources, can cause traffic issues, and can lead to harm of the surrounding environment. Secondly, accurate information about a system can reduce the number of emergencies and system down time (EPA, 2003). Being well acquainted with the assets allows utilities to know where problem areas are and address them promptly. This reduces expenses involved with emergency response and mitigates social and environmental issues.

AMPs also create more cost-effective solutions. The International Infrastructure Management Manual (IIMM) lists the benefits of AMPs, including repair costs that will lessen over time and increase savings on expected capital expenditure in long-term planning (2006). The continuous process of asset management optimizes service and minimizes costs over an asset's entire life (EPA, 2002). From the EPA's Fact Sheet Asset Management for Sewer Collection Systems, **Figure 1** shows the Asset Management Model.

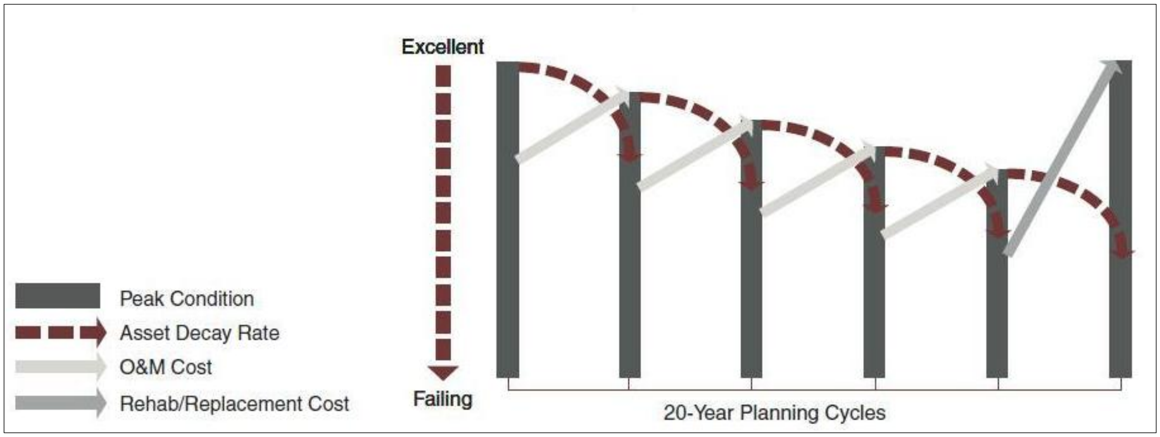


Figure 1: EPA's Asset Management Model.
Source: Environmental Protection Agency. (2002). Fact Sheet: Asset Management for Sewer Collection Systems. (EPA Publication No. 833-F-02-001). Washington, D.C.: U.S. Environmental Protection Agency. Used under fair use, 2014.

As shown in the figure, as the asset decays, the operation and maintenance cost (O&M Cost) over time stay consistent until the asset is ready for rehabilitation or replacement. This mode is more cost effective because it prolongs asset life as opposed to the Run-to Failure Management Model seen in **Figure 2** (EPA, 2002).

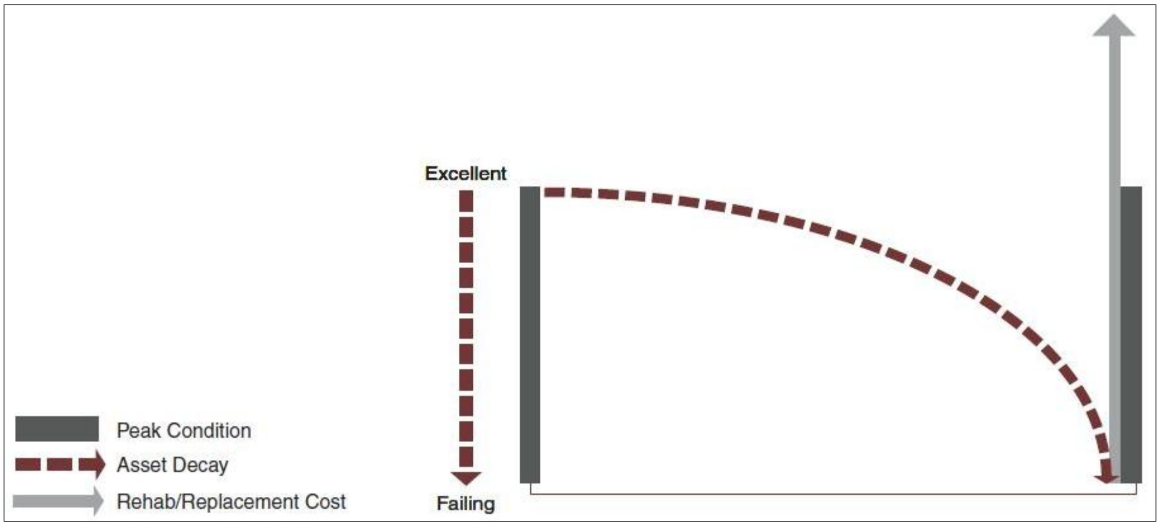


Figure 2: EPA's Run-to-Failure Management Model.
Source: Environmental Protection Agency. (2002). Fact Sheet: Asset Management for Sewer Collection Systems. (EPA Publication No. 833-F-02-001). Washington, D.C.: U.S. Environmental Protection Agency. Used under fair use, 2014.

Lacking adequate focus on operation and maintenance, sewer assets can deteriorate quickly. When assets deteriorate faster and fail unexpectedly, replacement can pose much higher costs financially (EPA, 2002). These unexpected failures can also pose public health and environmental health issues.

2.3 General Asset Management Process

According to the EPA, asset management consists of 11 elements (2002) while the IIMM lists 10 criteria that can conform to "core" or "advanced" levels of asset management (2006). However, there is much overlap between these two outlines. An important, and usually the first, step in asset management is to take an inventory of assets. Before management can commence, a utility must know how many assets they have, where they are locate, and what condition they are in. This information is necessary to beginning any AMP. The inventory is the first look at both the physical and financial status of the system (Association of Local Government Engineers of

New Zealand, et al., 2006). Another step in asset management is defining a LOS. The LOS is the expected performance of a system (Gay & Sinha, 2013). Before planning service can begin, goals and desired service levels need to be established. These will allow the utility to determine if its AMP is effective or if changes need to be made. It should be noted that AMPs are dynamic, and over time need to be adjusted as LOS change and new goals and initiatives are presented to or by the utility. Risk management is another key part of the asset management process. It is important for an AMP to identity and address risk associated with assets. Understanding the impact of failed infrastructure helps determine the criticality of assets and helps in the prioritization of replace and rehabilitation plans. Finally, as noted before, commitment to the AMP and its continuous improvement are extremely important to this type of management. The IIMM and the EPA stresses the importance of agreement among everyone involved in wastewater utility decision-making and that the plan must allow for changes to be made to adequately reflect the values of the utility.

2.4 AMPs Used in Practice

Across the country small and major utilities have begun to implement AMPs. Some larger utilities have whole task forces and hire asset managers to lead the utilities programs. Other utilities have worked with consultants to incorporate practices, while others have constructed and implemented their own plans. Two examples of organizations in the the US that have implemented AMPs are the New Mexico Environmental Finance Center and Village of Old Forge, NY.

2.4.1 New Mexico Asset Management Guide

In 2006, the New Mexico Environmental Finance Center (NM EFC) released a guide for water and wastewater utilities based on the approach presented in the IIMM and an EPA asset management guide and consulting experiences with utilities across New Mexico including small water systems. There are three major facets of this guide that stand out the most. One feature of the NM EGC guide is that it outlined the LOS criteria that should be considered before the implementation an AMP (NM EFC, 2006). The guide provides sample items that wastewater working groups should be deciding upon as they create an AMP for their utility. Items include maximum system flow, acceptable number of breaks per mile of pipe, and total storage capacity. A second feature of the NM EMC guide focuses on helping utilities determine criticality of their assets. Asset age, asset condition, and failure history are examples of the major criteria used to determine likelihood of failure (NM EFC, 2006). While cost of repair, social costs, legal costs, environmental costs, and reduction in LOS are examples of the criteria used to determining consequence of failure (NM EFC, 2006). The criteria for the likelihood of failure and consequence of failure are then used to create a criticality score. As seen in **Figure 3**, the guide suggests a 1 to 5 rating for the likelihood and consequences.

Multiplied		Consequence (Cost) of Failure				
		1	**2**	**3**	**4**	**5**
Probability of Failure	**1**	*1*	*2*	*3*	*4*	*5*
	2	*2*	*4*	*6*	*8*	*10*
	3	*3*	*6*	*9*	*12*	*15*
	4	*4*	*8*	*12*	*16*	*20*
	5	*5*	*10*	*15*	*20*	*25*

1	Very Low	4	High
2	Low	5	Very High
3	Moderate		

Figure 3: NM EFC Criticality Ranking System.
Source: New Mexico Environmental Finance Center. (2006). Asset Management: A Guide for Water and Wastewater Systems. Socorro, NM: New Mexico Environmental Finance Center. Used under fair use, 2014.

Like all risk or criticality rankings the scores have a level of subjectivity associated with them that allow institutional knowledge to be incorporated into the asset management process. As utilities document scores and their corresponding scenarios, patterns in scoring will help future workers that may have less experience to score assets more accurately. If the decision-making team does not agree with a score, the asset can always be re assessed (NM EFC, 2006). The third feature of the guide describes life cycle costing. This deals with understanding asset costs over time such as operation and maintenance, repairs, rehabilitation, and replacement (NM EFC, 2006). Cost of an asset is more than just its installation cost and major repairs. Knowing the life cycle cost of an asset helps in the scheduling and prioritization of projects. The guide is an excellent source of understanding how to apply an AMP and provides solutions to issues that arise in the implementation process.

2.4.2 Village of Old Forge, NY Wastewater AMP

The Village of Old Forge, NY recognized issues with their aging wastewater infrastructure. In 2006, the utility decided to invest time in creating an AMP to strategically address aging infrastructure issues and decrease the number of emergencies (OVFWTP, et al., 2008). The wastewater utility began their move to asset management beginning with educating the Town Board. The education process helped the Town Board understand the importance of wastewater collection and treatment and the importance of developing an AMP (OVFWTP, et al., 2008). The Village then followed the 5 steps presented by the EPA's handbook for small water systems: inventory, prioritizing assets, developing an AMP, implementing the AMP, and review and revise. To assist with data management, the Village employed the Total Electronic Asset Management System (TEAMS), software developed by Maryland Center for

Environmental Training for the EPA. TEAMS has the ability to organize and value assets, assign criticality and condition ratings, provide maintenance management functions, incorporate GIS, and produce reports (OLVWTP, et al., 2008). They've used TEAMS to help with inventory, prioritization, and develop capital improvement plans. TEAMS provides five different ranking features to determine criticality. First, there is a customer service ranking from 0, serves no critical customers, to 10, serves critical customers. Then, there are three '"impact of failure rankings:" overall process and safety, equipment and plant failure, and permit and environmental issues. Each are ranked for 0, no impact, to 3, high impact/total failure. Finally, there is a level of redundancy score from 0%, no backup to 200%, secondary backup. Together, the rankings are combined and produce a criticality report ranking from most critical to least. (OFVWTP, et al., 2008). TEAMs provides three ranking features for ranking condition of assets. First, assigning a condition rating from 0, new asset, to 5, almost unserviceable. Then, there is a capacity assessment, selecting undersized, does not meet requirements; full sized, meets requirement; or oversized, meets future requirements. Finally, there is a effective life consumed in which the utility selects a rating that depends on current condition, environmental conditions, maintenance history, and extent of needed service. Together, these ranking features combine to produce a condition report which ranks from the most unserviceable assets to assets in good shape. (OLDWTP, et al., 2008). The condition reporting allows the utility to have a formalized process to prioritize and make informed decisions regarding their systeme.

2.5 Theoretical Holistic Asset Management Framework

Introduced in Chapter 1, the asset management framework developed by Dr. Sinha incorporates basic elements that build on and complement one another to provide sustainable municipal infrastructure asset management. Unlike other asset management structures, this framework links standard asset management concepts, information systems, and sustainable and resilience management practices together. Ideally, this framework provides utilities with a support system that handles short and long term holistic asset management planning (Sinha & Eslambolchi, 2006). The framework is outlined in **Figure 4**.

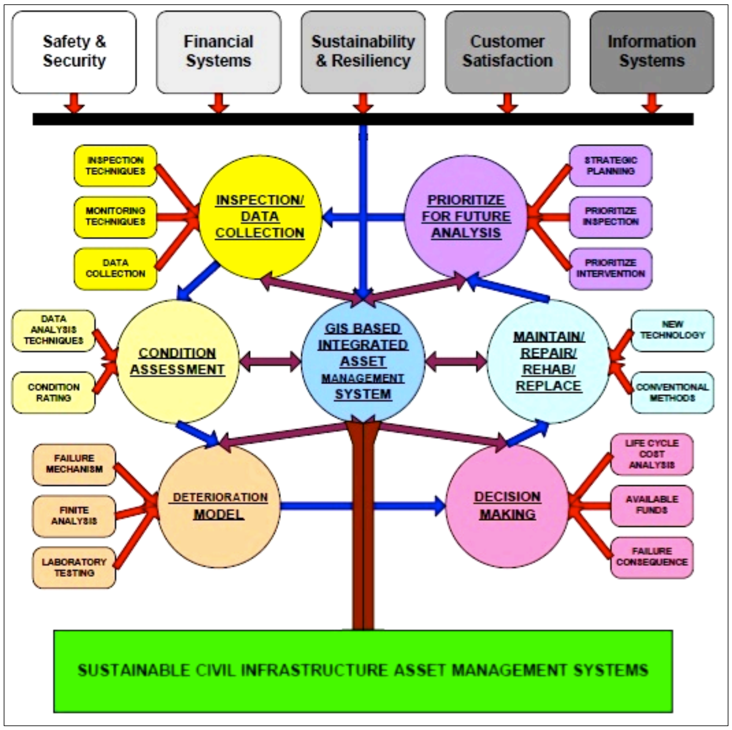


Figure 4: Holistic asset management framework.
Source: Gay, L. F., & Sinha, S. K. (2013). Performance, Sustainability, and Resiliency for Water Infrastructure Asset Management Primer. Unpublished manuscript, Virginia Polytechnic Institute and State University, Blacksburg, VA. Used under fair use, 2014.

The holistic asset management framework incorporates various aspects of asset management such as data collection, condition assessments, decision-making, repairs and maintenance, and future priorities into its strategic model. Like many asset management frameworks, most of the components in the framework support performance management. Alternatively, the holistic asset management framework incorporates sustainability and resilience management concepts into the asset management discussion (Gay & Sinha, 2013). Sustainability and resilience management, explained more in the next section, are needed for an asset management framework to be truly holistic. Performance focuses on the physical functioning of assets as they pertain to providing the desired LOS. Sustainability and resilience management concepts bring goals and standards to a utility that include the well being of the community and the environment as well as preparation for disaster. This holistic framework was used in this project as the baseline to compare the Town's current management plan to a strategic asset management framework. The ultimate goal of this project was incorporate holistic AMP practices into the Town's current management plan.

2.6 Three Aspects of Holistic Asset Management

As explained in the previous section, performance, sustainability, and resilience management are the three aspects of holistic asset management. **Figure 5** presents performance, sustainability and resilience management as the pillars in which water infrastructure management is supported according to Gay and Sinha (2013).

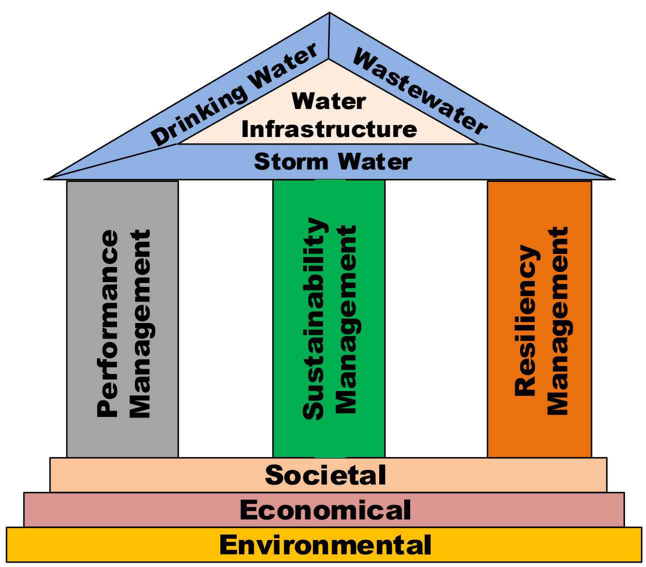


Figure 5: Three aspects of Holistic Asset Management.
Source: Gay, L. F., & Sinha, S. K. (2013). Performance, Sustainability, and Resiliency for Water Infrastructure Asset Management Primer. Unpublished manuscript, Virginia Polytechnic Institute and State University, Blacksburg, VA. Used under fair use, 2014.

By incorporating the three aspects into infrastructure management, utilities can provide indefinite services (Gay & Sinha, 2013).

2.6.1 Performance Management

Performance management is maintaining an acceptable level or service in the most cost-effective way (Gay & Sinha, 2013). Performance can be defined for a wastewater utility in terms of service life, operational costs, and reliability. Accurately measuring performance allows utilities to quantify goals and objectives, evaluate resource allocation, and provide feedback on the effectiveness of their program (Gay & Sinha, 2013). The previous sections describing asset management and its criteria, all support performance management. The physical condition and performance of the assets are the baseline for an asset management program. Performance is more readily quantifiable and routinely used to measure if the LOS is being met. However, as mentioned in the descriptions of the benefits of asset management it's also important for sustainability and for the robustness of the system to be actively measured or monitored. All of the steps in the holistic asset management framework are intended to sustain a given LOS and support performance management (Gay & Sinha, 2013), however, to have a truly holistic AMP, sustainability and resiliency need to be managed as actively as performance.

2.6.2 Sustainability Management

Sustainability management is maintaining a system that continuously satisfies need without compromising the ability of future generations to satisfy their own needs from the Triple Bottom Line (TBL) perspective (Gay & Sinha, 2013). Utilities in other countries, like the UK and Australia, have begun to adopt sustainable practices into their AMPs (Marlow, Beale, &

Burn, 2010 and Rees, Young, & Richardson, 2009). It has become globally important to address new world challenges linked to climate change, population growth, damage to ecosystems, and reduction of greenhouse gases. Because AMPs are always evolving, adding sustainability management to AMP goals and objectives can help utilities meet these challenges. Sustainability management can be implemented in small steps (Marlow, 2010). For example sustainability management practices can begin with goals in monitoring water and energy use, and can move to using green engineering principles, such as trenchless technologies.

The most important overarching goal of sustainability management is that in each decision-making step a TBL perspective be considered (Kenway, Howe, & Maheepala, 2007). **Figure 6** depicts elements of the TBL thought process.

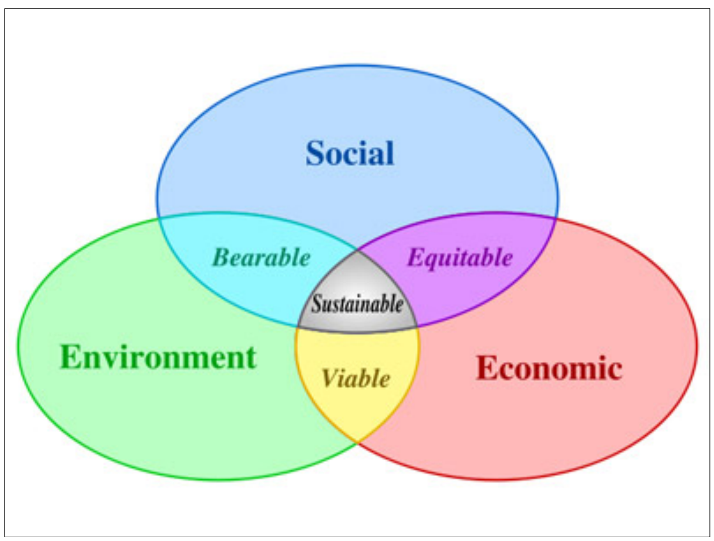


Figure 6: Visual representation of TBL perspective.
Source: Walker, E. (2010). The Triple Bottom Line for True Sustainability [Blog post]. Retrieved from http://elizabethgwalker.com/wordpress/2010/12/the-triple-bottom-line-for-true-sustainability/. Used under fair use, 2014.

Though the UK and Australia may be global leaders in sustainable asset management planning, the US EPA has designed a handbook for utilities to start to imbed sustainable goals into their planning and management of their water and wastewater infrastructure. They believe that the core mission of water and wastewater utilities is to provide clean and safe service that includes not just public health but environmental health and economic sustainability (EPA, 2012). The handbook helps utilities create goals and implement practices that incorporate TBL thinking into organizational practices.

Many researchers agree that setting TBL objectives within an AMP into can create more sustainable services. Allbee states that Americans have not always given enough thought about how present day decisions regarding sewer systems can impact the future (2005). However, because asset management helps in long term planning, planning for future wastewater needs and addressing future problems becomes part of every day thinking. Nevertheless, adding TBL principles to asset management help utilities address emerging issues due to climate change along with changing populations (Marlow, et al, 2010).

2.6.3 Resilience Management

Resilience management is the ability to avoid, reduce, mitigate, and ultimately recover from the effects of natural, accidental, or malevolent incidents with minimal impact on end-users (Gay & Sinha, 2013). Resilience management is often the most difficult management structure to add to any utility AMP. It begins with identifying what hazards to which the town could be exposed, and then making specific goals to address them. A deterioration model in the holistic asset management framework plays a major role in resilience management (Gay & Sinha, 2013). Deteriorating assets are more susceptible to disastrous events. The data collection model is intertwined with data for performance as well as sustainability. It is the analysis and implantation of the knowledge obtained that creates the support for each individual type of management.

2.7 Town of Blacksburg's Utility Management Program

The Town has suffered from sanitary sewer overflows during rain events. The Town's wastewater utility team has had to be on call and respond to alarms during the night and off hours. Sanitary sewer overflows are not only an expense to municipalities and a hassle, but also a public health concern and a violation of the Clean Water Act. Sanitary sewer overflows can be a result of the poor condition of sewer assets or inadequate capacity to pass rain derived infiltration and inflow (RDII). Instead of directly addressing condition and capacity issues before overflow events, the Town historically responded in a reactive manner. However, in 2006, the Town decided to undergo the first phase of a town-wide sanitary sewer study in an attempt to be proactive and less reactive in overflow events.

The objectives of the first phase (Phase I) of the study were to assess the capacity and condition of the wastewater collection system and to determine whether the collections system was in compliance with regulatory requirements (Wiley & Wilson, 2006). Dividing the Town into sewersheds, the capacity of the gravity sewers were ranked from the most capacity issues to the least. The report revealed areas with the most number of issues based on three customer based scenarios: current consumers, a 5-year growth projection, and a build-out under current zoning. Historical capacity issues are associated with RDII. Therefore, the study ranked sewershed capacity issues based upon four scenarios: dry weather flows, one-year storm flows, five-year storm flows, and 10-year storm flows. Capacity of pump stations was also evaluated. They were also ranked according to the same four scenarios as identified with the sewersheds (Wiley & Wilson, 2006). Condition of manholes and pump stations were ranked from poorest condition and most problems to best condition and fewest problems. The manholes were not ranked individually, but were grouped in sewershed (Wiley & Wilson, 2006).

Based on the results of the first phase of the study, a second phase (Phase II) was conducted to determine what impact remediation strategies would have on the overall system and minimize impacts to other portions of the system (Wiley & Wilson, 2006). Phase II of the study built upon the findings of the Phase I, specifically the identification of surcharges and overflows and the determination of the areas that were in need of repair. The second phase prioritized projects, prepared costs, and recommended a schedule (Wiley & Wilson, 2008). The results of the studies helped the Town prioritize proactive projects concerning the condition and capacity of the collection system. Phase I and Phase II helped the wastewater utility to create long term plans for asset renewal, collect and manage operational and performance data for condition and capacity, and initiate a more structured project priority ranking system to communicate with decision makers.

Chapter 3: Real World Framework Assessment and Parameter Development

In order to meet the objectives of this project, a literature review was conducted and a full review of the operational utility management of the Town was completed. An analysis process based on holistic asset management framework was outlined and a compiled list of data parameters for each management aspect (performance, sustainability, and resilience) was used to compare academic theory and real world practice.

3.1 Pre-Framework Analysis Procedures

Before the real world assessment of the Town using the holistic framework, an investigation of the Town's wastewater management and decision-making structure began. First, meetings were conducted with the Town's wastewater utility decision makers (Town Manager, department head of Engineering and GIS, department head of Finance, and department head of Public Works). These meetings were conducted to determine what data is used in the decision-making process for the Town's wastewater utility. A concept map of the Town's management structure can be found in **Appendix A**. After this initial outline, a full analysis of the utility using the holistic framework was performed.

3.2 Framework Assessment Process

An analysis process based on holistic asset management framework was performed with each feature of the holistic asset management framework. Starting with inspection and data collection, which according to Gay and Sinha is required for decision-making and all other steps in the framework depend on the availability and usefulness of the data (2013). The process of which was taken to analyze the Town's management procedures according to the holistic framework is displayed in flow process in **Appendix B**.

As seen in **Appendix B**, the analysis was broken down by the seven major elements of the holistic framework:

1. Inspection/Data Collection
2. Condition Assessment
3. Deterioration Model
4. Decision Making
5. Maintain/Repair/Rehab/Replace
6. Prioritize for Future Analysis
7. GIS Based Integrated Asset Management System.

After each element, three to four major questions are listed that were asked to determine how well the holistic framework is integrated into to real world management practices. For example, for inspection and data collection, the questions asked to determine if the Town incorporates that element of the holistic framework into their management structure included what data is collected, why is it being collected, where is the data being collected, and how is it supported? Through observation, communication, and day to day task, the results were recorded and discussed in the next chapter.

3.3 Development of Data Parameters

Necessary data collection is split into three different categories: performance, sustainability, and resilience. These three categories combined allow for a holistic AMP. In **Table 1**, the data parameters deemed necessary for a holistic AMP as compiled through literature and practice review are listed.

Table 1. Performance, sustainability, and resilience data parameters.

Performance Data	Sustainability Data	Resilience Data
1. Asset Identifier	1. Number of Customer Problem Reports	1.Location Relative to Hazards
2. Network/Group Name	2. Type of and Materials Used in Maintenance/Repair	2. Material Properties
3. Asset Type	3. System Energy Use	3.Environmental Hazards
4. Location	4. System Water Use	4.Security Hazards
5. Dimensions	5. System Overflows	5.Safety Hazards
6. Design Capacity	6. Predicted Future Service Level	6. Condition Rating/Likelihood to Fail
7. Design Flows	7. Long-term Plans	7. Maintenance/Repair Times
8. Installation Date	8. Customer Education Outreach	8. Age
9. Material	9. Green Alternative Considerations	9. Criticality Rating
10. Number of Maintenance/Repair Calls	10. TBL Costs	10. Probable Future Costs
11. Condition Rating and Inspection Date		
12. Total Daily Flow		
13. Peak Flow		
14. Rainfall/Precipitation		
15. Installation and Maintenance Costs		

3.3.1.Performance Management Data

Listed below are the explanations for each of the performance management data parameters used in this project. The fifteen parameters have been identified as some of the most important through literature and practice review, but are not the only performance parameters that could be collected.

1. Asset Identifier

The asset identifier is a unique name or number assigned to an asset. It is important to keep the identifier the same throughout the assets life, even if it is relocated (FCM, 2003). This allows any data attributed to the asset to always be attached to the asset. By ID'ing assets, monitoring the performance of the asset will be more streamlined. Any information accumulated regarding a particular asset will be accessible through its ID.

2. Network/Group Name

The asset network or group name is a way to classify the asset. Groups designated based on use of the asset (FCM, 2003). One example of a network/group is sewersheds. Sewersheds aggregate towns or cities wastewater assets based upon geospatial service areas. Projects can be prioritized based on sewersheds with the most issues or highest consequences of issues. This is important so when organizing different types of assets, assets for each group can easily be sorted.

3. Asset Type

The asset type is a label to understand what the asset is and what it does (Sinha, et al. 2013). For a sewer infrastructure, asset types include mains, manholes, laterals, and pumps. This data label is important in understanding what issues and what consequences those issues can have for each type of asset. Each asset type comes with its own set of possible issues. By being able to sort assets by type, utilities can look at and address all similar issues at once.

4. Location

Asset location is a very important attribute because it is vital for managing and analyzing assets. (FCM, 2003). However, there are multiple options for designating location. such as street addresses or latitude and longitude. Location can become complicated because some assets require single point location, like a pump, while others require more than one point, like a sewer line. The sewer line will require an end-to-end description as well as depth. Nevertheless, it is very important that a standard reference for all assets is used (FCM, 2003). Adopting a standard geospatial reference system, such as state plan coordinate systems allows for unique geospatial reference of assets.

5. Dimensions

Asset dimensions play important role in performance management, as dimensions are specific to each asset type (FCM, 2003). Understanding the size of the asset is needed in understanding the overall capacity of the system. Dimensions of an asset determine its ability to perform and are needed to understand if LOS can be met.

6. Design Capacity

The design capacity is a function of dimensions and properties of an asset (FCM, 2003). In order to understand how much the asset can handle, the design capacity needs to be known. Capacity includes the ability to handle daily flow as well as provide storage for large storm events. It will be used as a benchmark to determine whether or not the asset is underperforming or not. This is also useful in understanding that even if the asset is performing at its best, it may not have the capacity for the desired level of service. This information will be important when evaluating the system and creating goals for the LOS.

7. Design Flows

The design flow is usually generated by hydraulic modeling and is a key attribute to have (FCM, 2003). The design flow, like the design capacity, is a benchmark to monitor the assets and how they are performing. Design flow is used to help determine if the current assets can handle the expected daily flow and meet the desired LOS.

8. Installation Date

The age of an asset is important in understanding its design life (FCM, 2003). Even though the age of an asset may not be a determinant of the actual condition, it is key indicator for issues that emerge as an asset ages. Asset age may also indicate how the asset was made (material properties, thickness, etc.). It is important to be aware of those issues as well as when any issue is resolved by rehab or replacement, thus changing the install date.

9. Material

The material of as asset should be recorded. Understanding asset material allows a utility to better understand rehabilitation decisions (FCM, 2003). The material can be an indicator for how long the asset can perform.

10. Number of Maintenance/Repair Calls

A log of maintenance and repair calls allows utilities to make better decisions by gaining a better understanding of how often a job is being performed on an asset. By maintaining this data, utilities can find trends that will help them prioritize their projects (FCM, 2003). Individual assets or areas of assets with the largest number of calls are indicative of suboptimal performance. This would indicate that replacement or rehabilitation of these assets may be needed.

11. Condition Rating and Inspection Date

Using a standardized approach that has been adopted by the utility, a numerical condition rating should be given to assets, recorded, and dated. As long as the utility has adopted one condition rating scale and that is understood amongst departments (preferably with an index published that is easy to access), then the rating system itself does not matter (FCM, 2003). These ratings play a large role in understanding of risk and prioritizing projects.

12. Total Daily Flow

Total daily flow is the total volume of water in a 24hr period (FCM, 2003). This data allows the utility to monitor how much volume is moving through the system. The determination of whether the volume is higher, lower, or expected is needed when considering the performance of an asset. This can be used to determine if desired LOS is being met, and also if the design flow and design capacity of an asset is being used to its potential.

13. Peak Flow

Like total volume, peak flow values help utilities monitor the performance of an asset and is needed to evaluate the overall capacity of a system. However, this parameter may only be necessary at certain points in the system (FCM, 2003). Peak flow is important to determine if the design capacity of the assets has the ability to withstand the peak flow and also if the asset is under performing during extreme conditions.

14. Rainfall/Precipitation

Rainfall data is a useful indicator of conditions and assist in the design of future facilities. This information is important in understanding RDII in the system (FCM, 2003). RDII plays a large role in design as the system needs to be able to have the capacity to continue to perform even when levels may be higher than normal due to rain events. Large amounts of RDII can also indicate poor condition of an asset and will help determine if that asset is higher in priority for rehab or replacement.

15. Installation and Maintenance Costs

Installation and maintenance costs are the baseline for an assets total cost. Total costs are important for developing infrastructure renewal and replacement. Estimated values are a good starting point, but more precise values provide better information. (FCM, 2003). By starting with the known value of installation and continuing to monitor maintenance costs utilities can better financially plan and capture comprehensive costs to provide services. These costs include direct cost of activities and the resources consumed (materials, labor, contracted services, equipment; installation cost) (EPA, 2002).

3.3.2 Sustainability Management Data

The list below describes the data parameters used in this project for sustainability management.

1. Number of Customer Problem Reports

Understanding customer problems is an indicator of poor service, but also a service that is not lasting (FCM, 2003). By managing and addressing customer issues, new TBL approaches can be made to repair the assets in question. When a customer has called a problem, a disruption of normal social activity has occurred. The number of customer problems shows a high social cost that could lead to a high economical cost if not addressed promptly and efficiently.

2. Type of and Materials Used in Maintenance/Repair

Similarly to the need to record the number of maintenance and repair calls for performance management, the type of maintenance and the materials used is needed in sustainability management to help make better decisions. Assets requiring extensive repairs indicate that the asset is not sustainable. There is also an accumulation of waste from materials used in maintenance jobs. Assets with many repairs take priority, and using TBL thinking, more sustainable repairs/replacements can be made.

3.System Energy Use

Monitoring energy use can be used to reduce the total energy used in the collections process. By making efforts to reduce energy, this practice could not only cut costs, but also create a more sustainable system (EPA, 2012). Infrastructure less dependent on energy satisfies the communities wastewater needs without using larger amount of fossil fuels reducing pollution and the long-term reliance.

4. System Water Use

Monitoring water used in maintaining the wastewater collections system cannot only benefit the environment by making efforts to reduce water consumption, but with reduced water can come reduced energy use (EPA, 2012). Water may be used to seal pumps and is used to flush systems for cleaning when blockage occurs or before lining pipes. Energy and water audits combined create a more sustainable system cutting costs and reduce pollution and unnecessary water consumption.

5. System Overflows

System overflows negatively affect the environment and society by releasing waste into streets, homes, fields, parks, etc. Record of system overflows allows utilities to readily address issues and prioritize asset rehab/replacement projects based on consistent overflows. Addressing system overflows and understanding where they are happening more often can lead to a more sustainable system once they are resolved.

6. Predicted Future Service Level

Understanding the needs 1, 2, 5, 10, even 20 years out can help utilities determine the capacity needs of their communities (Association of Local Government Engineers of New Zealand Inc. & Institute of Public Works Engineering Australia, 2006). Using predictive modeling, utilities can start to understand how their system will need to change as population, development, and environmental law changes.

7. Long-term Plans

Like predicting need, having long-term plans for assets will help address issues before they occur. Having a plan for assets for an extended time creates a more sustainable and reliable system even after a generation has left (EPA, 2012).

8. Customer Education Outreach

Helping customers understand their wastewater impact can play large roles in asset management. Teaching customers to waste less and what not to put down wastewater systems helps create a safer and more efficient sanitary sewer system. Tracking who has been impacted can allow a utility to adapt capacity needs into the future.

9. Green Alternative Considerations

Knowing what green alternatives might be available when maintaining and repairing assets is an important tool to have. Though not all green alternatives are cost-effective, utilities can try to balance their environmental impact with cost-effectiveness by knowing and understand the alternatives and linking them with certain assets (EPA, 2012).

10. TBL Costs

Understanding total financial cost is one aspect of TBL thinking. However there are more costs than just installation, repair, and maintenance. There are also environmental and social costs. These costs need to be evaluated and added to the equation for the best decision making practices.

3.3.3 Resilience Management Data

The resilience management data parameters used in this project are listed below.

1. Location Relative to Hazards

Understanding the location of the assets is essential in the resiliency of a system. Knowing where the asset is located allows the utility to understand what hazards may be associated with it.

2. Material Properties

The material properties help understand risks associated with an asset. (Gay & Sinha, 2013). Similar to understanding location, knowing the material of the asset can also be linked to certain hazards such as corrosion from different soil types as well as vulnerability to damage from digging.

3. Environmental Hazards

Environmental hazards include hazards that can affect the asset as well as those that the asset can affect such as bodies of water. Environmental factors also include weather. Storms can be damaging to sewer systems and quick response to having systems back online is imperative.

4. Security Hazards

Security hazards include malicious acts and social behaviors. Both can impact a system and create problems. Identifying security hazards may be more sensitive to certain times of year (e.g. prominent speaker comes to town for college gradation, game days). These times may indicate more people in area or non-typical behavior and could cause problems.

5. Safety Hazards

Safety hazards can include buildings, road, and unsolicited digging; any danger that could come to a system that is caused by human. Like environmental and social hazards it is important to know safety hazards associated with an asset so to limit as many issues as possible.

6. Condition rating/Likelihood to fail

Condition rating is necessary to evaluate how soon an asset can fail. Understanding potential failures is essential to knowing how resilient the system is. The condition rating takes into consideration risks like corrosive soil, construction hazards, etc. Low condition ratings to number assets, especially assets in a close proximity suggest that the system will not be able to bounce back quickly if there is any kind of disruption.

7. Maintenance/Repair Times

Like condition rating, knowing how fast an asset is repaired indicates how resilient the asset and system are. Repairs that can be performed quickly suggest that the system, though disrupted, maybe able to bounce back quickly. Recorded repairs that take longer and may be more extensive help in the prioritization of projects.

8. Age

Though asset age can't always tell condition of a pipe it does give some indication of how long it can last. Some assets that may be every old may still have a long service life, but this data parameter can help group assets and rank them. Older assets may not be able to bounce back from disruption as quickly as new assets because older materials or parts may not be readily available. Also, the asset may not be as accessible as newer assets because newer assets, generally, have been strategically placed for current day plans whereas older assets maybe in harder to reach places because of landscape changes over time.

9. Criticality rating

A criticality rating identifies, how severe a failure of an asset is to the overall system. Would a whole section of town be affected? Would an environment be affected? Would someone of importance be affected? This rating can help utilities prioritize not only repair and maintenance needs, but monitoring needs as well (Old Forge Wastewater Treatment Plant and NYSDEC Facility Operations Assistance Section, 2008).

10. Probable Future Costs

Understanding the costs associated with individual assets and groups of assets are necessary in creating a resilient system. This also includes a depreciated value that can be calculated from standard formulas and replacement costs (FCM, 2003). To create a more resilient system, expenses may increase and that is key information in decision making and prioritizing.

3.4 Creating a Work Process Flow

Once gaps were identified, recommendations based on initial theoretical research were made. A work process flow was created based on the current practices of the utility and was integrated with recommendations to bridge the gap between academia and practice. The work process flow was created in order to help the Town understand and more easily implement the suggested management changes. A work process flow illustrating the Town's current management process can be seen in **Appendix C.**

Chapter 4: Real World Assessment Results and Outcomes

Each feature of the theoretical holistic asset management framework was compared to the processes conducted by the Town to manage its wastewater assets. Then, the Town's collected data parameters were compared to the list of necessary parameters in performance, sustainability, and resilience. The results of the assessments are described below and major gaps have been identified.

4.1. Inspection and Data Collection

The Town has a series of velocity flow meters and pump station data loggers that measure gravity pipe system flows and influent flow into pump stations on a daily basis. The Engineering and GIS department is in charge of the data collection, and Public Works is in charge of responding to alarms. These meters and data loggers are closely monitored and are becoming an essential part of the maintenance and operation of the wastewater assets around the Town. An example of an area velocity meter is seen below in **Figure 7.**

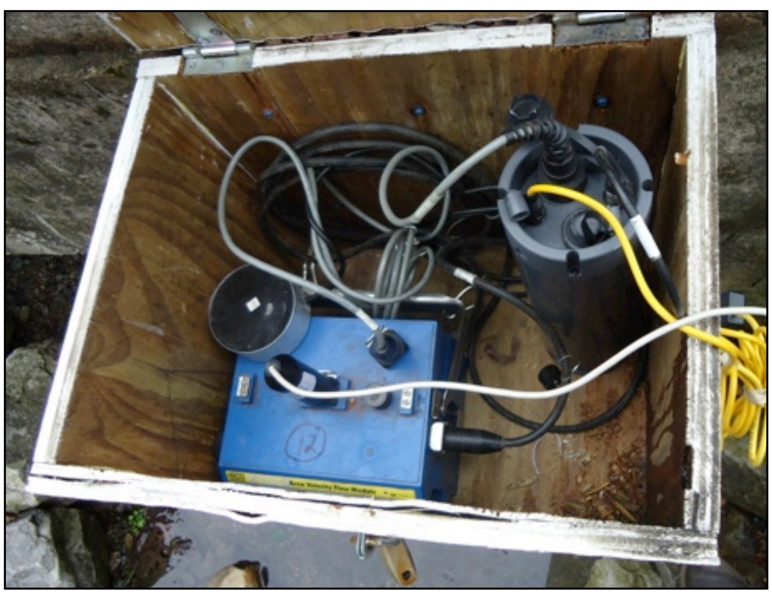


Figure 7: Example of velocity flow meter data logger

In **Figure 8** below, is an example of a pump station data logger is shown.

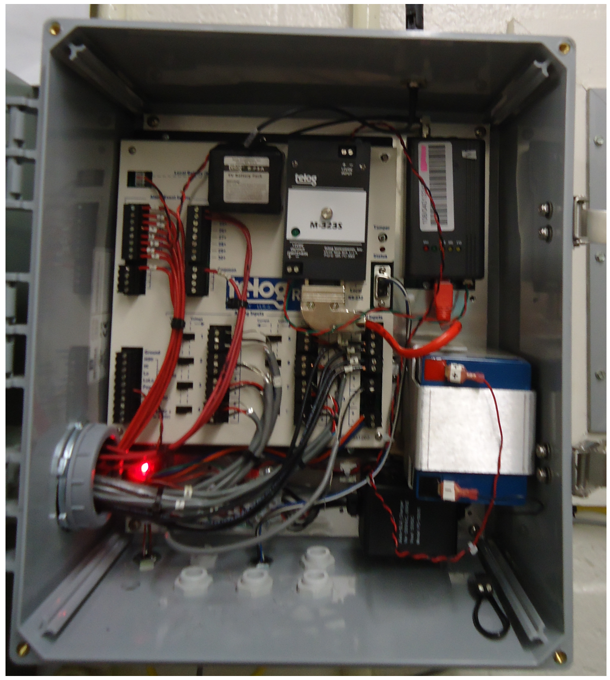


Figure 8: Example of pump station data logger

The Town currently has 15 velocity flow meters and 23 pump stations data loggers.

The flow meters are spaced across the Town in different sewersheds. As seen in **Figure 9**, the Town is divided into 13 major sewer sheds. These sewersheds help divide the Town and organize projects.

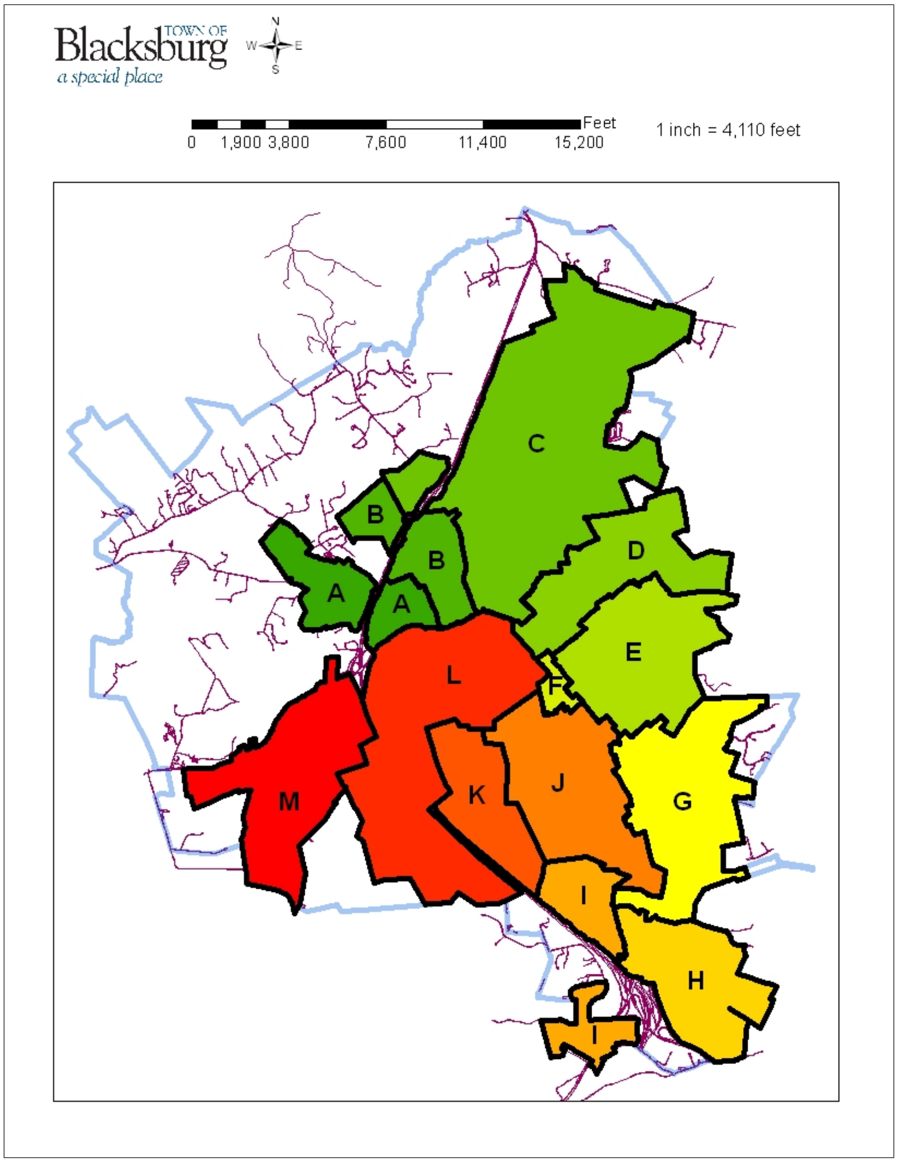


Figure 9: Town of Blacksburg's major sewersheds

Theses velocity meters monitor the capacity of the gravity sewer lines. Most velocity meters are connected to a cellular modem allowing the data to be sent automatically to a Telog Enterprise Client® (TEC) data management server that is hosted by the Town. In Figure 10, the flow meters, indicated by the orange pin symbol, are identified through The Town.

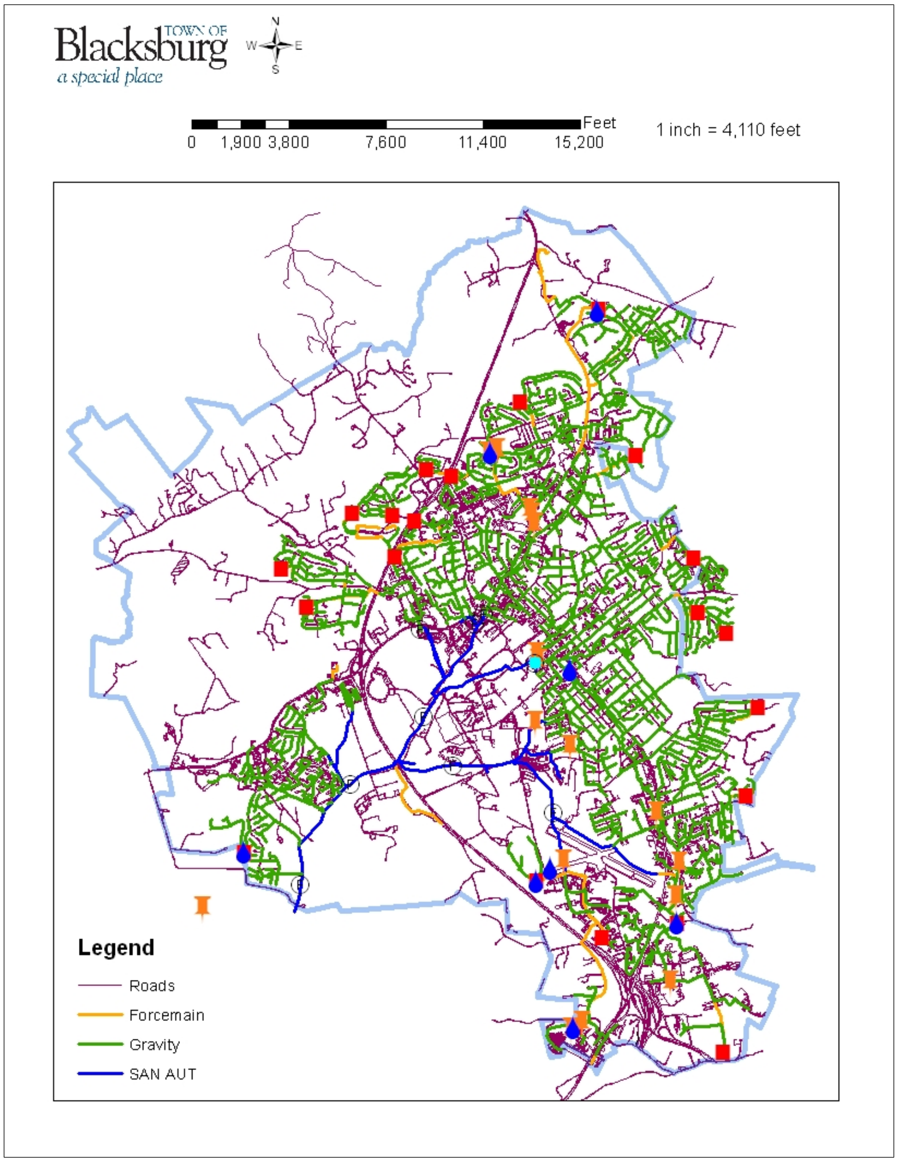


Figure 10: Town of Blacksburg's flow meters and sewer pipelines

All data from the meters and data loggers in the system are stored in the TEC database. TEC allows the data to be analyzed and exported for external analysis and modeling.

At each pump station in the Town, data loggers have been installed. The complexities of these monitoring devices vary depending on installation date and the initial severity of issues at that pump station. The simplest devices are amperage clips connected to Telog data loggers. The amperage clips record the flow of electricity to the pumps to indicate if a pump is running and for how long. More complex devices monitor the hydrostatic level in wet wells using a submerged pressure transducers. The more complex devices also identify alarm conditions to the Public Works Department. Issues include high wet well level, pump station power loss, and monitoring devices failures. The installation of the various complexity of devices were dependent on the sanitary sewer study and affordability. The Town is striving to have pressure sensors at all pump stations.

The Town’s Public Works Department collects everyday maintenance and operations data in a Cartegraph™ database. Cartegraph™ is a tool used for work orders. The type of work order and the asset(s) addressed are indicated. The labor, materials, and equipment are also selected and are associated with prices. This system allows the Town to see where, how often, and what type of work was completed on various assets. Cartegraph™ is also linked with GraniteXP, which Public Works uses for inspections.

Granite XP is integrated with the Town’s closed-circuit television (CCTV) inspections. While the workers are conducting CCTV surveys of sewer assets, they can pause the video to indicate cracks or other issues. When the recording is uploaded to Granite XP, pauses in the video are marked making it easy for viewers to locate the problems found during inspection instead of re-watching the entire feed. Granite XP allows the Town to associate the recording with specified assets in the GIS. Linking the video to geospatial reference allows workers to view the condition of the assets and identify specific locations where issues were discovered.

4.2 Condition Assessment

Using the data from the field loggers, the Town employs SewerGEMS, a calibrated, hydraulic, dynamic model, to evaluate system performance under multiple scenarios that vary between customer demands and storm events. **Figure 11** shows an example of dry weather and wet weather modeling at a pump station in the Town.

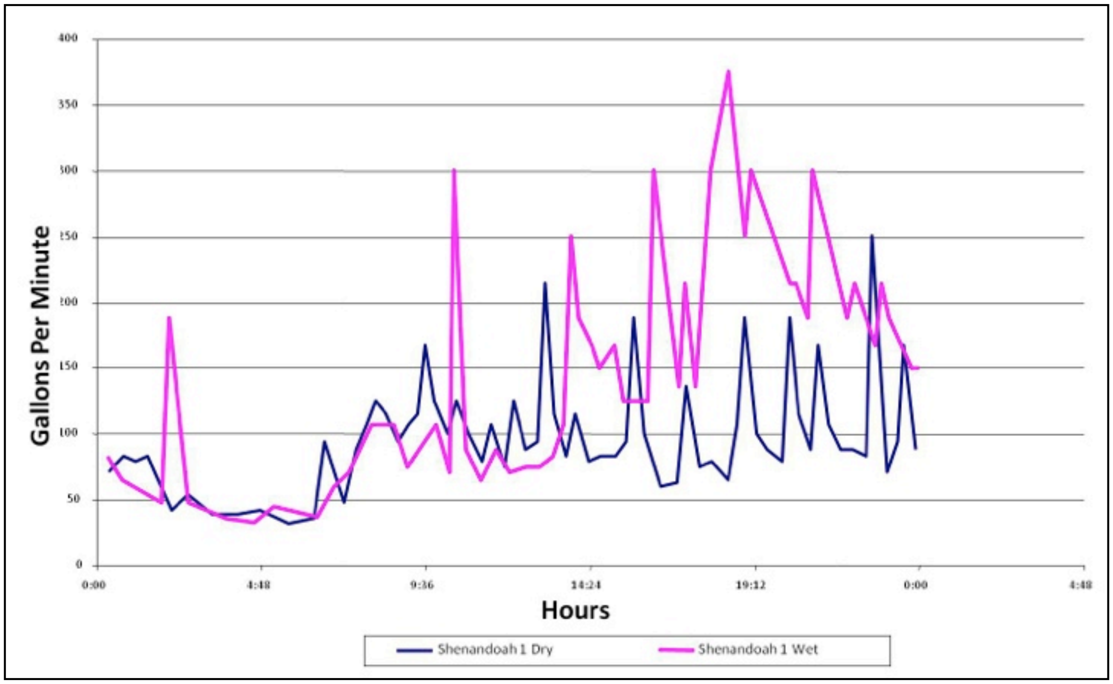


Figure 11: An example model of a Town's pump station daily flow.

The model, similar to the one in the figure, plays an important role in the rehabilitation and repair of assets. Without the model, the Town would not be able to make well-informed decisions about its assets and about addressing any issues that may arise.

The Town evaluates the condition and capacity of the sewer system by using the information provided by inspections and data collection and SewerGEMS model scenarios. Inspection data helps the Town better understand the condition of its system. The information provided by the SewerGEMs mode is used to project consequence of capacity failures in the system with various scenarios. Together information gathered to understand the condition and capacity of the system results in an annual list of capital projects needed to renew system performance.

4.3 Deterioration Model

At this time the Town does not employ a deterioration model. According to research, these types of models are the most difficult to implement into a utility because an adequate model is difficult to create (Gay & Sinha, 2013).

4.4 Decision Making

Depending on the level of significance of the issue, decision-making is made by different people involved in the Town's wastewater utility. For everyday tasks and maintenance, Public Works and the Engineering Departments make decisions based on their data collection and models. For larger, more extensive projects, often Capital Investment Projects, Engineering, Public Works, and Finance come together to help prioritize and plan. Collectively they present the projects to the Town decision-makers. Though Town Managers and Town Council are ultimately in charge of final decisions, it is a collective effort of all departments to present the best data and reason for projects through the organization's Capital Improvement Projects program.

4.5 Maintain, Repair, Rehabilitate, and Replace

The Town's sanitary sewer study provided the Town with options for maintenance, repair, rehabilitate, and replacement projects. The study helped prioritize those projects as well. Using their data and an understanding of the consequences of the condition of different assets in the collection system, the Town makes decisions on whether to continue to maintain and repair or if a rehabilitation or replacement project is necessary. These decisions are made with a combination of severity of the asset failing and the money available to address the issues.

4.6 Prioritize for Future Analysis

A risk ranking system based upon the likelihood of a failure versus the consequence is used to prioritize the annual list of capital projects. Data collected by the Engineering and GIS department are used to assign the likelihood of failure, and organizational leadership sets the severity of consequences.

	Probability Level				
Severity Level	A-Frequent	B-Probable	C-Occasional	D-Remote	E-Improbable
I - Extreme	AI	BI	CI	DI	EI
II – High	AII	BII	CII	DII	EII
III - Moderate	AIII	BIII	CIII	DIII	EIII
IV – Low	AIV	BIV	CIV	DIV	EIV

Figure 12: The priority matrix ranking system used by the Town for capital projects.
Source: Wiley & Wilson. (2008). Town of Blacksburg, Virginia Sanitary Sewer System Study: Phase II. Comm No. 207055.00. Wiley and Wilson, Lynchburg, VA. Used under fair use, 2014.

As seen in **Figure 12**, the ranking system helps the Town identify issues that have higher risk of disrupting the present LOS. The priority matrix prevents as many system failures as possible and helps build a proactive decision-making management style.

Capital costs to restore the capacity and condition of the sewer system are projected over a ten-year period, using the information from the Town's data collection and inspections, sewer modeling, collaboration of departments, and priority matrix. Actual project costs and system performance data are reviewed on a regular basis to determine if the program objectives are being met and to update the list of projects in the priority matrix.

4.7 GIS Based Integrated Asset Management System

Data from sewer lines, manholes, data collection sites, pump stations, and water meters are entered into the Town's GIS databases. This data is used to identify the location of assets, classify conditions, record incidents, and prioritize renewal capital construction projects. **Figures 13** provides an example of how the Town uses GIS to better view and understand its wastewater system by dividing the system into sewer-subsheds, indicating the location of pumps stations and data loggers, and color-coding sewer pipe line type.

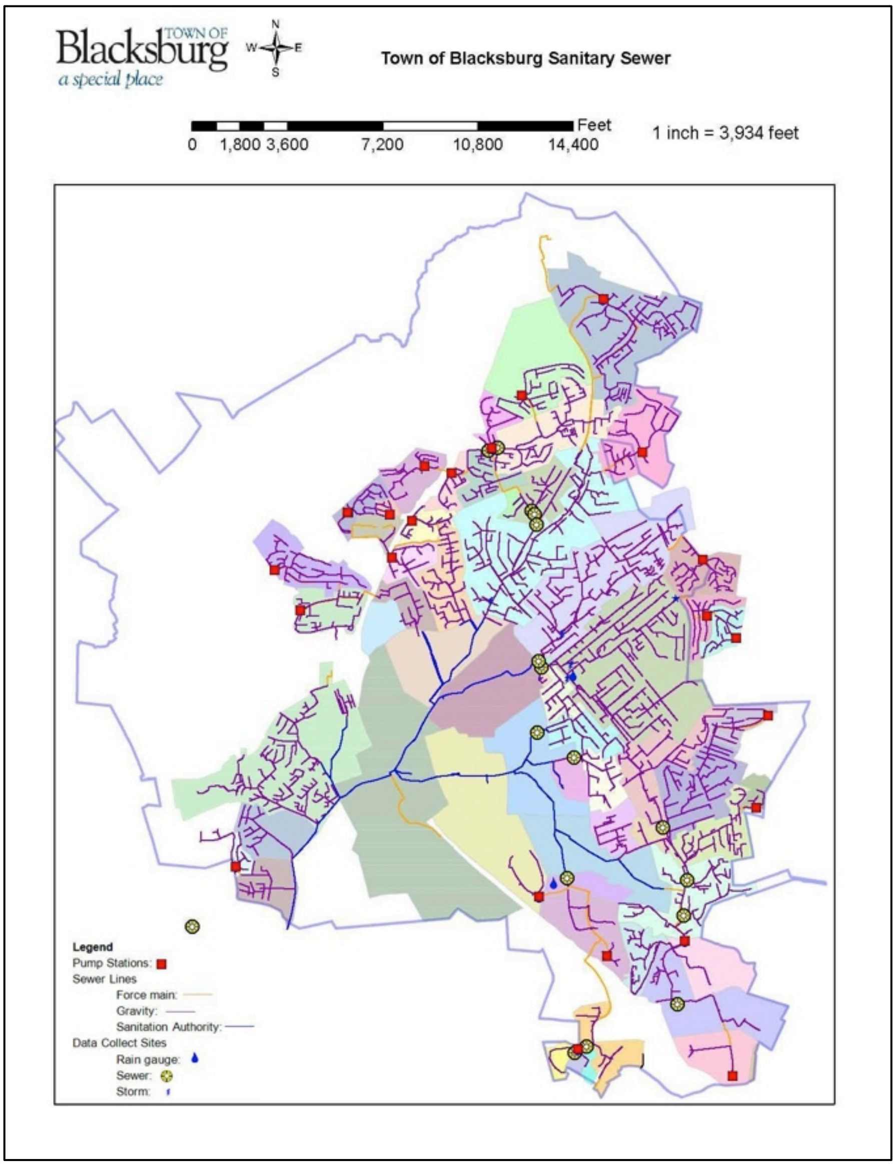


Figure 13: An overall map of the Town of Blacksburg's wastewater system

Many utilities across the country struggle with not knowing the location of their assets, which often makes it impossible for them to maintain a prescribed level of service. By employing the use of GIS, the Town has a comprehensive database of its assets that can easily be updated and changed.

Location of assets is one of the important aspects of asset management. By understanding where assets are located, an understanding of the system can begin. The Town's GIS Department is responsible for supporting the wastewater management by maintaining the geospatial location of assets and analysis. Most data collected by the Town is linked to the GIS database (see more explanation for what types of data in the next section). The GIS tool allows the management of assets to be linked by location and by parameters like type, material, expenses, and flow. These are all important parameters in a well-practiced asset management program.

4.8 Performance, Sustainability and Resilience Management Data

A good AMP is more than just data collection. However, proper data collection is the first step in beginning a useable AMP. To have a holistic AMP, data collection must fall into three categories: Performance, Sustainability, and Resilience as discussed early. Through literature and practice review data parameters for each management aspect were determined. They are listed below and recorded with whether or not the Town is currently collecting the data on an regular basis in an organized manner. Because a GIS database is essential to maintaining a holistic AMP, it is also recorded in the chart if the data parameter is stored in the Town's GIS database.

In **Table 2**, the performance data needed in a holistic AMP is listed. The Town collects 12 out of 15 desired parameters. However, not all of those parameters are stored in GIS. The table shows what the parameters are, if they are collected, if they are stored in GIS, and if there is a complete set stored in GIS. The Town collects many data parameters however, they are often stored in different databases other than GIS, thus there is not a complete listing in GIS.

Table 2. Important performance management data parameters

Performance Data	Collected?	In GIS?	Complete?
1. Asset Identifier	Yes	Yes	Yes
2, Network/Group Name	Yes	Yes	Yes
3. Asset Type	Yes	Yes	Yes
4. Location	Yes	Yes	Yes
5. Dimensions	Yes	Yes	No
6. Design Capacity	Yes	No	No
7. Design Flows	Yes	No	No
8. Installation Date	Yes	Yes	No
9. Material	Yes	Yes	No
10. Number of Maintenance/Repair Calls	Yes	No	Yes
11. Condition Rating and Inspection Date	Yes	Yes	No
12. Totally Daily Flow	Yes	No	No
13. Peak Flow	Yes	No	No
14. Rainfall/Precipitation	Yes	Yes	No
15. Installation and Maintenance Costs	Yes	No	No

In **Table 3**, the data parameters for sustainability management are presented. Like the performance data table, this table indicates if the parameter is collected, stored in GIS, and if the there is a complete set of data stored in GIS.

Table 3. Important sustainability management data parameters

Sustainability Data	Collected?	In GIS?	Complete?
1. Number of Customer Problem Reports	Yes	No	No
2. Type of and Materials Used in Maintenance/Repair	Yes	No	No
3. System Energy Use	No	No	No
4. System Water Use	No	No	No
5. System Overflows	Yes	No	No
6. Predicted Future Service Level	Yes	No	No
7. Long-term Plans	Yes	No	No
8. Customer Education Outreach	No	No	No
9. Green Alternative Considerations	No	No	No
10. TBL Costs	No	No	No

The results in **Table 3** indicate that, even though there are fewer parameters required, the Town does not collect as many for sustainability as performance management parameters. According to literature, this is common in most utilities. However, to be more holistic more sustainable practices must be adopted. According to research by Marlow, Beale, and Burn, many utilities have deemed sustainability as important, but most utilities lack the data collection in this area (2010). Of the parameters collected by the Town, none are stored in GIS. However, it could be argued, that the parameters of long-term planning and predicted future service levels are not suitable for being store in GIS by asset.

Table 4 contains the resilience parameters and shows that the Town collects half of the desired parameters. Like the sustainability parameters, there are fewer required than in performance, and again the table indicates the same items as in the previous tables.

Table 4. Important resilience management data parameters

Resiliency Data	Collected?	In GIS?	Complete?
1. Location Relative to Hazards	Yes	Yes	No
2. Material Properties	Yes	Yes	No
3. Environmental Hazards	No	No	No
4. Security hazards	No	No	No
5. Safety hazards	No	No	No
6. Condition rating/Likelihood to fail	No	No	No
7. Maintenance/Repair Times	Yes	Yes	No
8. Age	Yes	Yes	No
9. Criticality rating	No	No	No
10. Probable Future Costs	No	No	No

Identifying hazards that the assets can be exposed to is a very important data parameter to collect. However, the Town does not directly collect any of this hazard data. These hazards also encompass a number of different factors. Environmental hazards, for example, can be animal habitats or assets buried in corrosive soils. Because most identifying asset data is in GIS, it can be easy to locate if a man-made hazards like buildings or other environmental hazards like bodies of water. Nevertheless, this is not officially collected and stored with asset information.

The total costs of assets are a critical data parameter for all three aspects of asset management because it helps determine the life-cycle cost of the asset. Understanding the money already put into an asset and how much more is needed in repair and replacement is necessary for good decision making. Weighing the economic burden of how much an asset costs that may be under continuous repair versus a full replacement is very important in long term planning and decision-making. To see all of the data parameters currently collected by the Town view the mind map, "Town of Blacksburg Data Collection Outline," in **Appendix D.**

4.9 Work Process Flow

In order to help the Town integrate a holistic AMP into their everyday practice, a work process flow has been designed. The proposed work process flow can be seen in **Appendix E**. As previously mentioned, the current work process flow can be seen in **Appendix C**. In the proposed work process flow (**Appendix E**), the holistic asset management framework has been integrated into the Town's current practice to show how implementing the framework would work. This work process flow differs from the current because it integrates all data collection in the GIS database and includes a deterioration model in the risk -based decision-making. The processed process also incorporates both technical leaders and Town decision makers in defining likelihood of events and defining consequences for decision-making. However, in both work process flows, the data parameters associated with a holistic AMP have been divided into five working groups: commissioning data, operation and maintenance data, monitoring data, planning data and financial data. These working groups are used to help the Town understand roles and responsibilities of each department involved in the wastewater utility. The breakdown of each working group and the parameters associated with the group can be seen in **Table 5**.

Table 5: Working groups and associated data parameters.

Working Group	Data Parameters
Commissioning data	Asset Identifier, Network/Group Name, Asset Type, Location, Dimensions, Design Capacity, Design Flow, Installation Date, Material, Location Relative to Hazards, Material Properties, Environmental Hazards, Security Hazards, Safety Hazards
Operation and Maintenance data	Condition rating and Inspection Date, Number of Maintenance/Repair Calls, Number of Customer Problems Reports, Type of and Materials Used in Maintenance/Repair, Condition Rating/Likelihood to Fail, Maintenance/Repair Times, Age, Criticality Rating
Monitoring data	Total Daily Flow, Peak Flow, Rainfall/Precipitation, System Energy Use, System Water Use, System Overflows
Planning data	Predicted Future Service Levels, Long-term Plans, Customer Education Outreach, Green Alternatives Considerations,
Financial data	Installation and Maintenance Costs, TBL Costs, Probable Future Costs

This division of data parameters helps incorporate all three aspects of asset management into the various stages of asset life and management.

The work process flow in **Appendix E** illustrates how the data collect impacts the condition assessment and the deterioration model after being input in the GIS. Then, it moves from results of condition assessment and a deterioration model to decision-making. Next, decision-making information moves to project prioritization based upon risk exposure matrix that has been developed by technical staff assessments of likely scenarios and decision maker input on resulting consequence. If the asset is in a state of low risk, regular maintenance is continued and the procure is repeated. If the asset condition falls below an acceptable level of risk then it is decided if the asset is repaired, rehabilitated, or replaced. The information from the condition ranking and risk matrix is used to prioritize for the future projects and the cycle starts again.

Chapter 5: Conclusion and Recommendations

After the assessment of the Town's wastewater utility using the holistic asset management framework gaps between academia and practice have been identified. To help bridge those gap several recommendations have been made to the Town to help adapt its management practices.

5.1 Conclusion

Literature review has found that holistic asset management provides better decision making for utilities. A holistic AMP provides short and long term support for wastewater assets. It involves TBL thinking that allows efficient decision making economically, socially, and environmentally. Holistic AMPs also provide emergency prevention by using a proactive response system. However, to utilize a holistic AMP, data collection is vital.

The Town of Blacksburg has moved from a reactive management program to a more proactive one after a comprehensive sanitary sewer study in 2006. The Town has inspection and data collection systems in place to help support the maintenance of their assets. By monitoring of their assets, the Town better understands the condition and capacity of the system. However, they do not employ a standard condition rating that incorporates the data they collect. The Town lacks a deterioration model for their assets. However, academia cannot yet help provide a deterioration model for utilities that is reliable and encompasses all factors in the deterioration of assets. This type of model may not be feasible, but adopting a simple model based upon heuristic parameter could help the utility make more proactive decisions and prevent emergencies.

Decision-making is dependent on the magnitude of the issue. For large-scale projects, a collective interdepartmental decision-making process that involves Public Works, Engineering and GIS, and Finance Departments is required. The Town utility does use its collected analyzed data to come to optimized conclusions. This includes the prioritization of maintenance, repair, rehabilitation, and replacement of assets. Nevertheless, a more streamlined and concentrated data collection and analysis process would provide the Town with more substantial information regarding the life of their assets. In combination with their risk ranking system and a projection of capital costs over ten years, the Town is able to prioritize projects for the future. Again, with more quality data collection and analysis, the utility will be able to provide even better risk rankings and project prioritizations. GIS is a platform used by the Town for much of its data storage. However, it is not the center of the management system. The theoretical framework states that by centering the AMP on a GIS database platform, it can coordinate all steps involved in the management process and allow the Town easier data access and evaluation for decision-making and projections for the future.

The Town focuses more of its data collection on performance, which is essential in any AMP. However, academia stresses to truly have a holistic AMP, a utility needs to focus on collecting and managing more sustainable and resilient data parameters. A more holistic approach to asset managing allows for better decision-making and creates more sustainable system.

The creation of a holistic AMP and work process flow for the Town's wastewater utility provides a framework that may be implemented to include all community services. **Figure 14** provides a picture of how the Town envisions departments working together to implement holistic AMP through all service divisions. It highlights that currently, the Town is working on the wastewater's AMP and it focuses mainly on performance data.

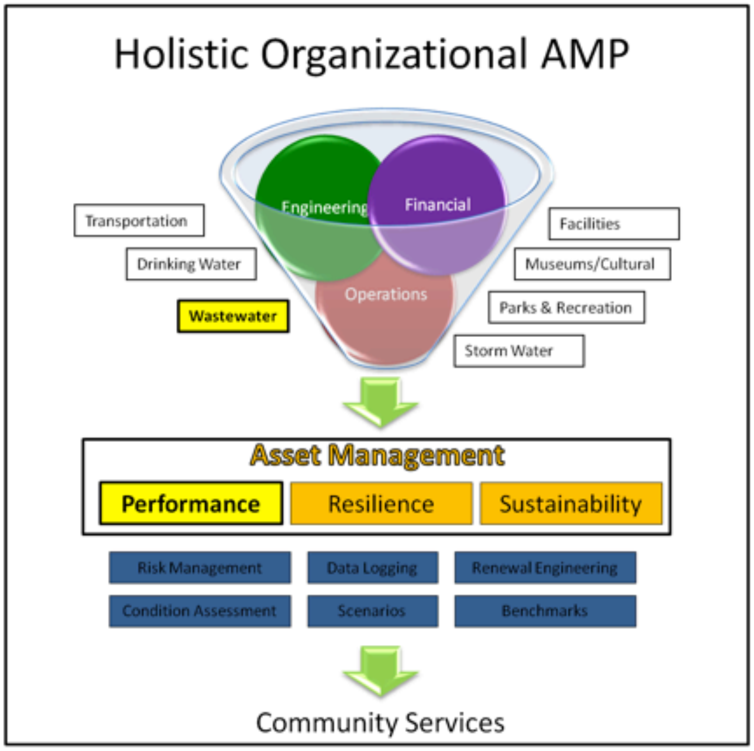


Figure 14: The Town of Blacksburg's future holistic organizational AMP. Source: Stolte, M. (Eds.). (2013). Proceeding from UIM Asset Management Conference 2013. WaterID: Real-Life Benefits of Information Sharing and Reporting. Arlington, VA: Benjamin Media, Inc. Used under fair use, 2014.

If the holistic AMP can be successfully applied in the wastewater utility, it can easily be adapted to the other services provided by the Town. The fundamental ideas of holistic AMP can move, the Town from performance-based management in the wastewater sector, to performance, sustainability, and resilience management in all services, such as drinking water, transportation, stormwater, and facilities

5.2 Recommendations

In order for the Town to adopt a holistic AMP, several suggestions have been made in order to prepare and help transition for the shift in management style. Most of these recommendations are reflected in the work process flow for the Town.

5.2.1 Survey of All Assets

Because having an inventory of all assets is key to starting an AMP, it is suggested that the Town finishes its collection of basic asset data such as location, type, materials, dimensions, installation dates, and initial costs. It is also important for this data to be imported in the GIS database for easy access and information processing. From there, the Town will have a good baseline for implementing a holistic AMP.

5.2.2 Goal Setting and LOS

In order to utilize a holistic AMP, the Town's wastewater utility much first create goals in performance, sustainability, and resilience as well as determine the LOS desired. Both the EPA and IIMM guides state that goals setting and agreeing upon the LOS is second to inventory when beginning to implement an AMP. To have a holistic AMP, goals need to be incorporated in the three aspects not just performance. Once goals and the LOS are set, a holistic AMP can be outlined and implemented.

5.2.3 Simple Deterioration Model

To help with decision-making and proactive response, adopting a simple deterioration model maybe a good addition to the Town's AMP. Though deterioration models are not widely accepted and most cannot encompass the complexities of wastewater asset deterioration, academia is working towards finding suitable models. The model presented in work by Duchesne et al. (2012) and Syachrani et al. (2011), are examples of models designed for wastewater utilities. Even though, both research groups state some bias in their models. However, models like these are something the Town should consider evaluating the application of such approaches moving forward.

5.2.4 Condition and Criticality Rating Systems

To better assess condition and understand consequence of failures, incorporating a standard condition rating and criticality rating system would be helpful to the Town. The Town currently employs a simple condition rating system that is not currently linked to GIS. Implementing more complex rating systems like the ones used by New Mexico utilities and the Village of Old Forge as described in Chapter 2 may assist better decision-making for the Town.

5.2.5 Energy and Water Audit

To begin more sustainable practices and to achieve sustainable benchmarks, the Town should complete an energy and water audit of their assets. These audits are much more associated with pump stations rather than other assets due to energy to run pumps and other pump station equipment as well as water used for pump seals. Understanding energy and water usage of these assets is an example of implementing TBL thinking and an attainable goal for the Town to set.

5.2.6 GIS Tool for Identifying Hazards

The hazard data parameters presented in Chapter 3 are not an easy data parameters to collect. However, integrating a indication system in GIS to identify hazard types and a ranking system of to prioritize severity levels would help the Town to understand hazards associated with their assets. Presented at the UIM Conference in Arlington, VA in 2013, the Virginia Beach

Utility in coordination with the consulting group Arcadis presented their work to create a condition and criticality ranking system for water main that integrated into GIS and visually showed areas at high, medium, and low priority. The criticality rankings incorporate social, economic, and environmental scores use to determine final criticality scores (Ihye, 2013). This concept could be adapted for sewer pipeline and would help the Town make better-informed decisions about their assets and prioritizing projects.

Works Cited

Ihde, D. (Eds.). (2013). Proceeding from UIM Asset Management Conference 2013. *Distribution System Desktop Condition, Risk, and Replacement Planning*. Arlington, VA: Benjamin Media, Inc.

Allbee, S. (2005). America's pathway to sustainable water and wastewater systems. *Water Asset Management International,* 1 (1), 9 – 14.

Association of Local Government Engineers of New Zealand, National Asset Management Steering Group, Institute of Public Works Engineering Australia. (2006) *International Infrastructure Management Manual (IIMM).*(3rd ed.) Wellington, N.Z.: National Asset Management Steering (NAMS) Group

Duchesne, S., Guillaume, B., Vileneuve, J., Toumbou, B., & Bouchard, K. (2012). A Survival Analysis Model for Sewer pipe Structural Deterioration. *Computer-Aided Civil Infrastructure Engineering,* 28, 146 – 160.

Environmental Protection Agency (EPA). (2012). *Planning for Sustainability: A Handbook for Water and Wastewater Utilities*. (EPA Publication No. 832-R-12-001). Seattle, WA: Ross & Associates Environmental Consulting, Ltd.

Environmental Protection Agency. (2008). *Asset Management: A Best Practices Guide.* (EPA Publication No. 816-F-08-014). Washington, D.C.: U.S. Environmental Protection Agency.

Environmental Protection Agency. (2003). *Asset Management: A Handbook for Small Water Systems*. (EPA Publication No. 816-R-03-016). Washington, D.C.: U.S. Environmental Protection Agency.

Environmental Protection Agency. (2002). *Fact Sheet: Asset Management for Sewer Collection Systems*. (EPA Publication No. 833-F-02-001). Washington, D.C.: U.S. Environmental Protection Agency.

Federation of Canadian Municipalities and National Research Council (FCM). (2003). *Best Practices for Utility-Based Data*. Ottawa, Ontario: Federation of Canadian Municipalities and National Research Council

Gay, L. F., & Sinha, S. K. (2013). *Performance, Sustainability, and Resiliency for Water Infrastructure Asset Management Primer.* Unpublished manuscript, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Kenway, S., Howe, C., & Maheepala, S. (2007). *Triple Bottom Line Reporting of Sustainable Water Utility Performance.* Denver, CO: American Water Works Association.

Marlow, D. R. (2010). Sustainability- Based Asset Management in the Water Sector. In J. E. Amadi-Echendu, K. Brown, R. Willett, & J. Mathew (Eds.), *Definitions, Concepts and Scope of Engineering Asset Management* (216-275). New York: Springer.

Marlow, D., Beale, D., & Burn, S. (2010). Linking asset management with sustainability: Views from the Australian sector. *Journal American Water Works Association,* 102 (1), 56 – 67.

Marlow, D., Person, L., Whitten, S., MacDonald, D. H., & Burn, S. (2010). Linking asset management to sustainability though risk concepts: the role of externalities. *Water Asset Management International,* 6 (3), 21 - 28

New Mexico Environmental Finance Center. (2006). *Asset Management: A Guide for Water and Wastewater Systems*. Socorro, NM: New Mexico Environmental Finance Center.

Old Forge Wastewater Treatment Plant and NYSDEC Facility Operations Assistance Section. (2008). *Wastewater Infrastructure Asset management Plan Village of Old Forge.* Albany, NY: Village of Old Forge.

Rees, A., Young, T., & Richardson, I. (2009). Change and asset management in wastewater utilities – a UK perspective. *Water Asset Management International,* 5 (4), 3 – 7.

Santora, M., & Wilson, R. (2008). Security and Preparedness – Resilient and Sustainable Water Infrastructure. *Journal – American Water Works Association,* 100 (12), 40 – 42.

Sinha, S. K., & Eslambolchi, S. S. (2006). *Bridging the Gap: An Educational Primer on Sustainable Water Infrastructure Asset Management.* Unpublished manuscript, Pennsylvania State University, University Park, PA.

Stolte, M. (Eds.). (2013). Proceeding from UIM Asset Management Conference 2013. *WaterID: Real-Life Benefits of Information Sharing and Reporting*. Arlington, VA: Benjamin Media, Inc.

Syachrani, S., Jeong, H. S., Chung, C. S. (2010). Dynamic Deterioration Models for Sewer Pipe Network. *Journal of Pipeline Systems Engineering and Practice,* 2, 123 -131.

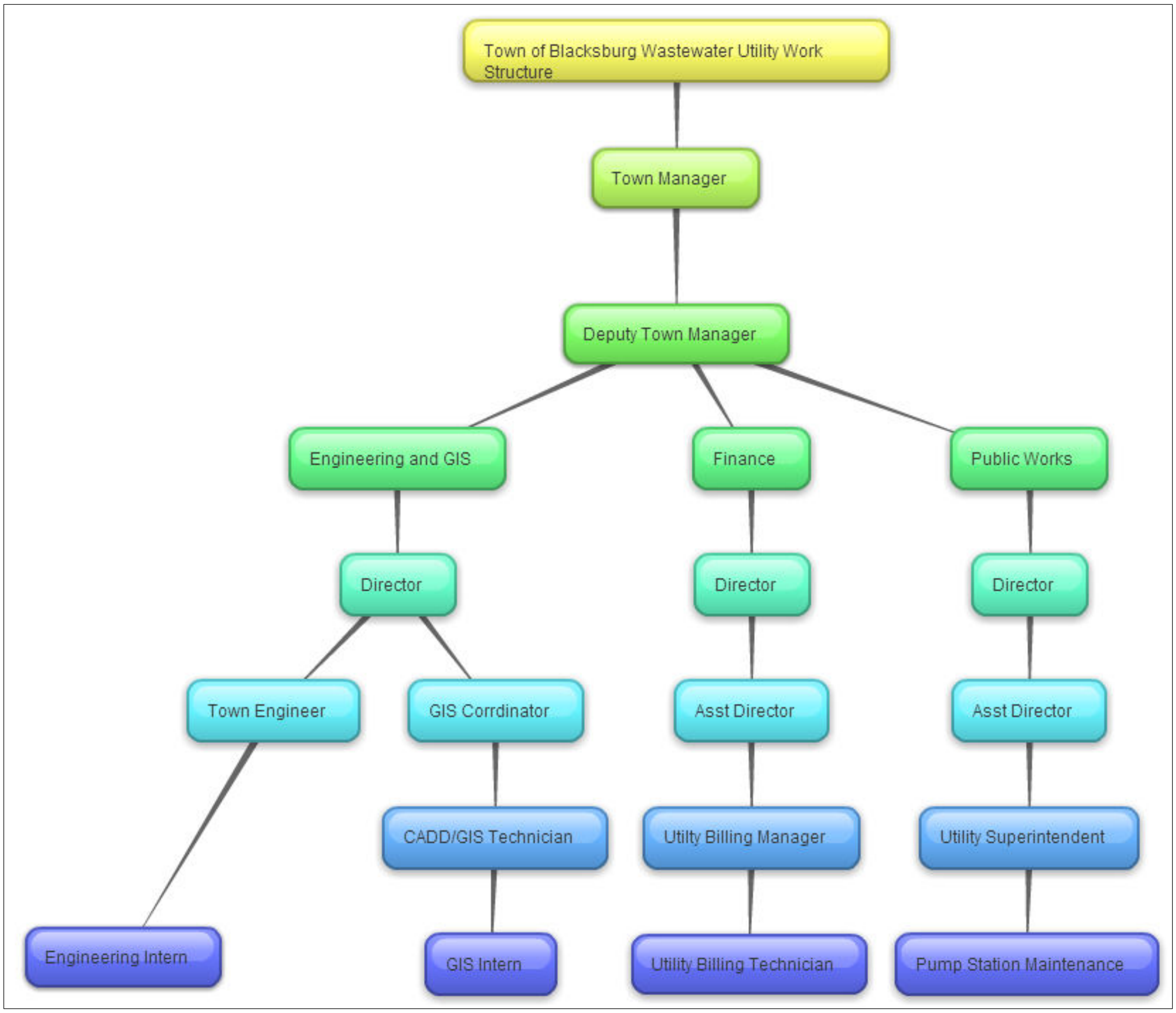
Utility Infrastructure Management (UIM). (2008).*Guide to Water and Wastewater Asset Management.* Peninsula, OH: Benjamin Media, Inc.

Wiley & Wilson. (2006). *Town of Blacksburg, Virginia Sanitary Sewer System Study: Phase I.* Comm No. 205079.91. Wiley and Wilson, Lynchburg, VA.

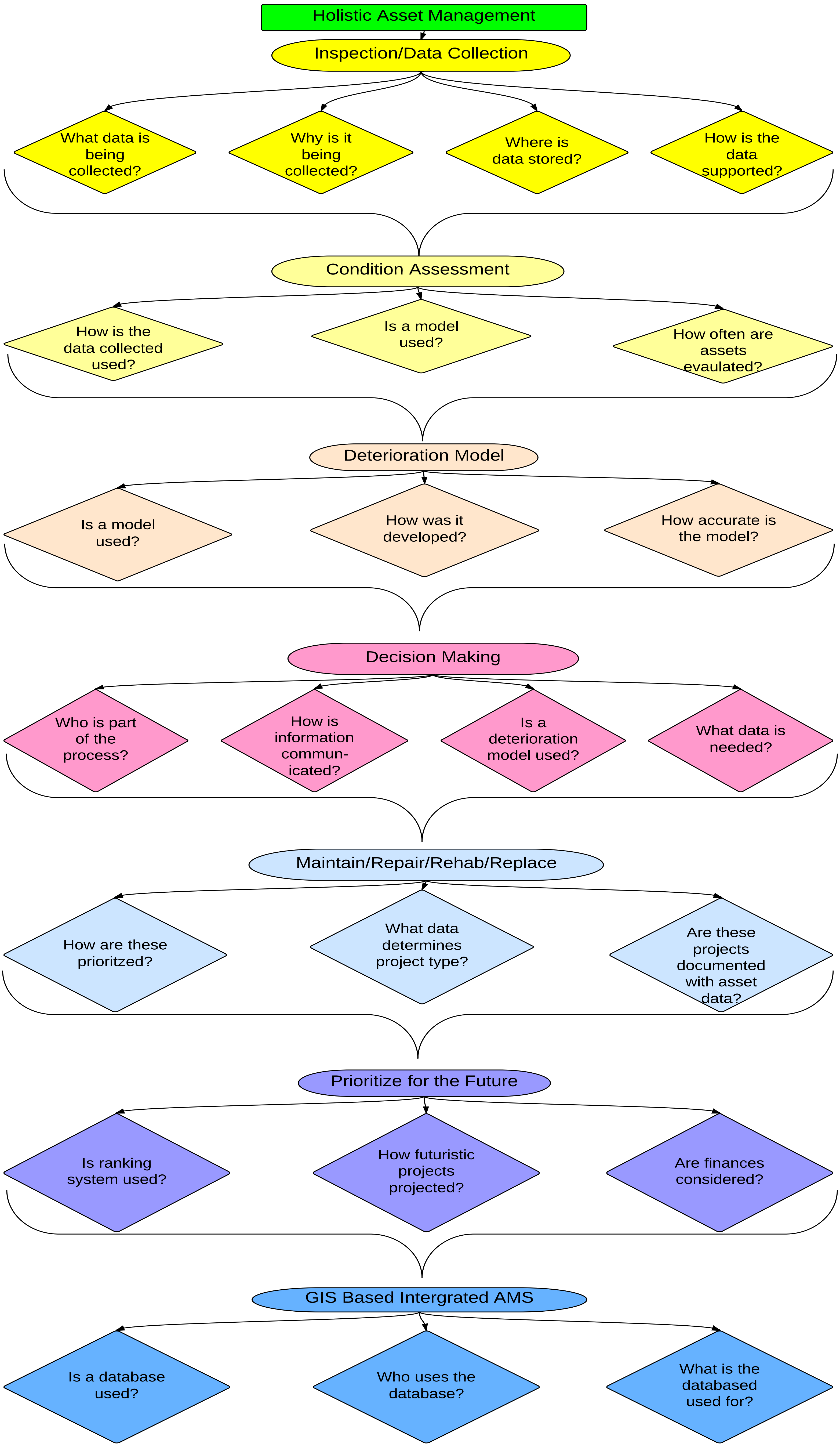
Wiley & Wilson. (2008). *Town of Blacksburg, Virginia Sanitary Sewer System Study: Phase II.* Comm No. 207055.00. Wiley and Wilson, Lynchburg, VA.

Williams, W., Jones, M., & Stillman, J. (2013). Asset Management: How US utilities can leverage international experience. *Journal - American Water Works Association,* 105 (5), 86 – 91.

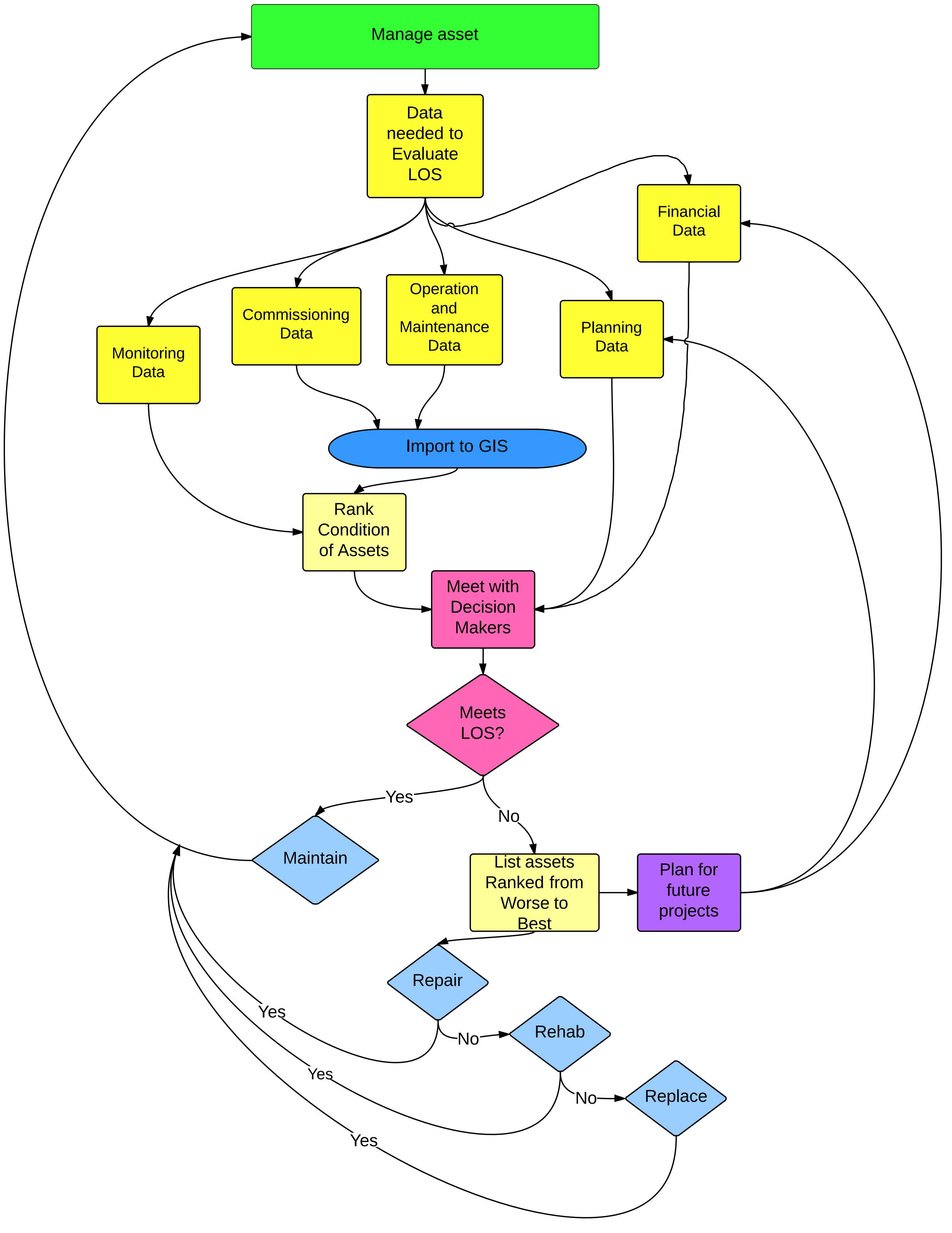
APPENDIX A: Town of Blacksburg's Wastewater Utility Management Structure

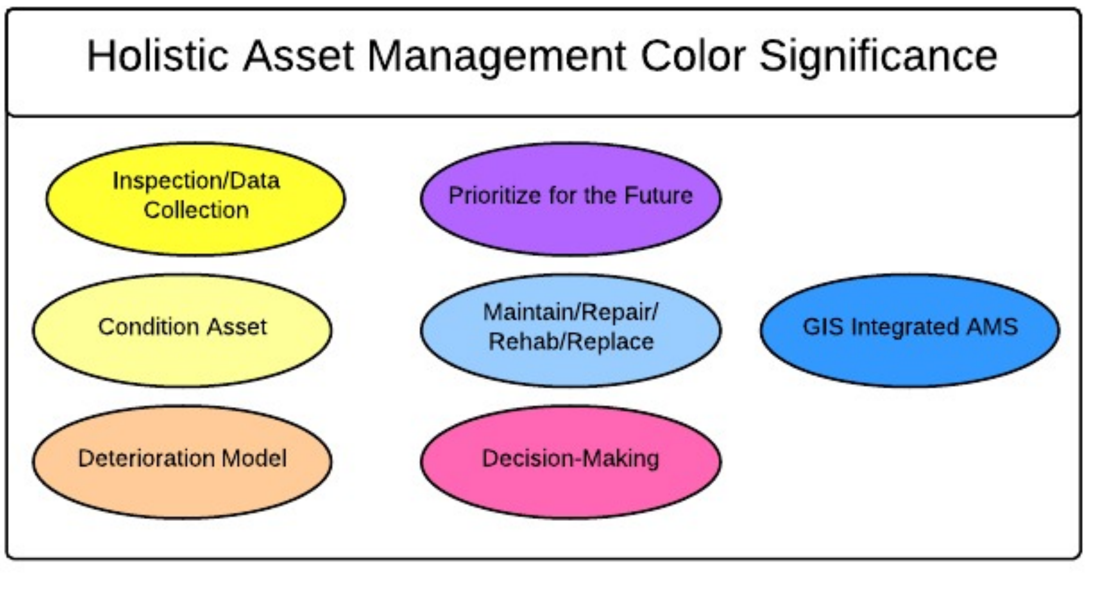


APPENDIX B: Holistic AMP Framework Assessment Flow Chart

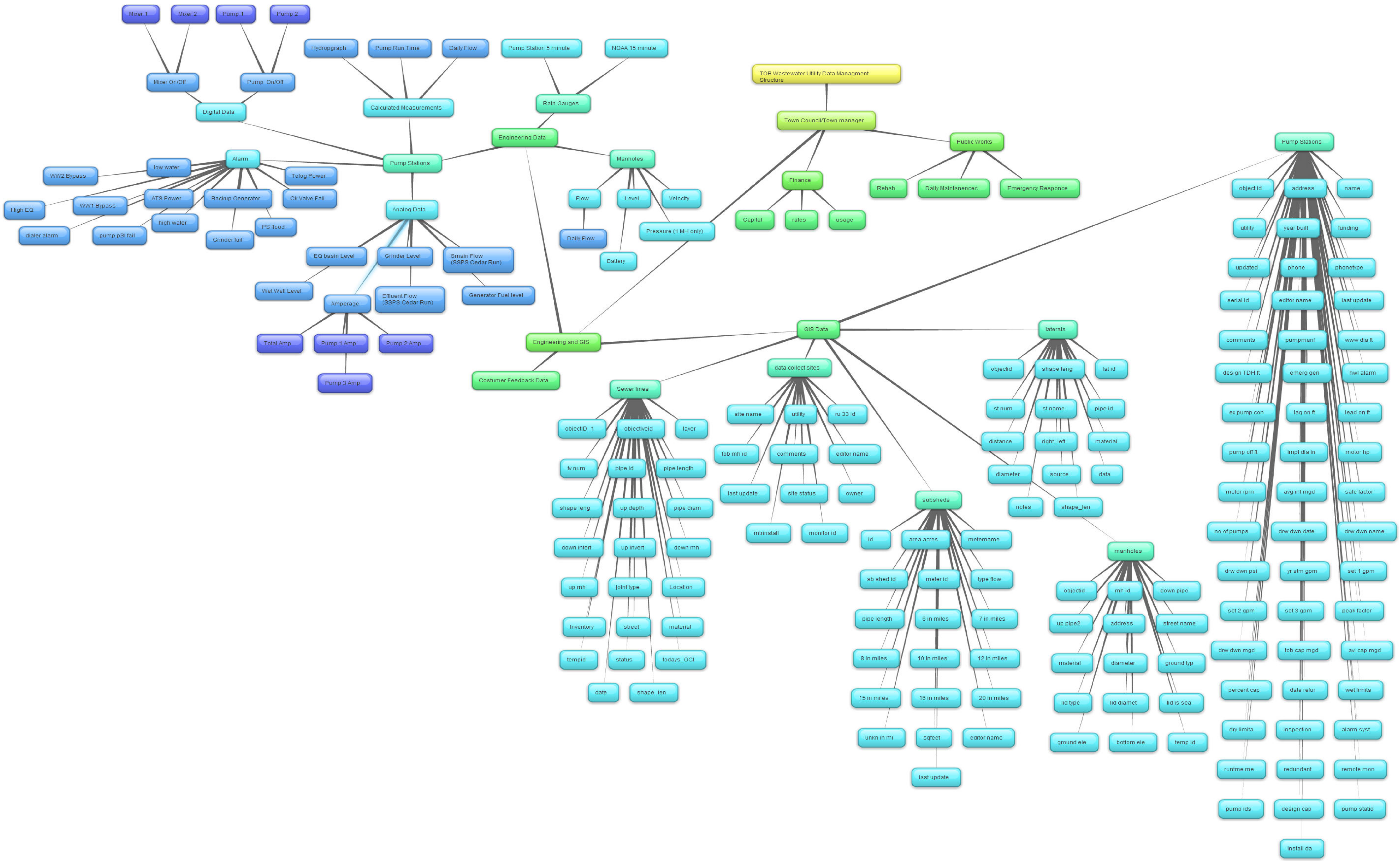


APPENDIX C: Current Town of Blacksburg Wastewater Utility Work Process Flow





APPENDIX D: Town of Blacksburg Data Collection Outline



APPENDIX E: Proposed Holistic AMP Work Process Flow for the Town of Blacksburg Wastewater Utility